Scanning tunneling microscopy analysis of surface diffusion on semiconductors

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Introduction

In the last few years scanning tunneling microscopy (STM) has proven to be a unique tool for the analysis of surface diffusion phenomena at the atomic scale. In this talk two prototypical examples of surface diffusion on highly reconstructed semiconductor surfaces will be reviewed. In the first example the Si(111)-(7x7) surface was chosen to study the diffusion of single Pb adsorbates. This surface has very recently unveiled its potentiality to act as a template for the growth of well ordered nanocluster arrays [1-3]. The thermal mobility of single Pb adatoms on Si(111)-(7x7) surfaces has been analyzed from high temperature, i.e. slightly above room temperature(RT) [4], to low temperature (as low as 40 K) [5-6]. In the second example, the diffusion of single adatom vacancies on the Ge(111)-c(2x8) will be discussed [7]. These vacancies were artificially created with the STM by well-controlled tip-sample contacts [8-9].

Experimental details

The experiments were carried out in an ultra-high-vacuum (UHV) system equipped with a home-made variable temperature scanning tunneling microscope [6,11]. This STM, connected to a continuous flow liquid He UHV cryostat, allows imaging at sample temperatures in the range of 40K to 400K.

Results and discussion

Pb/Si(111)-(7x7): While at high temperature, the diffusion of single Pb atoms to neighboring half-cells of the (7x7) reconstruction can be observed in STM measurements [4], below RT, single Pb atoms remain completely trapped inside the half-cells but thermally activated motion between different sites inside them can be resolved at temperatures in the range of 100K to 130K. In particular, three regions of preferential adsorption inside each half-cell have been detected and atomic jumps between them have been observed in STM movies as illustrated in Fig 1. By combining STM experiments at low temperature with first-principles calculations [5] a detailed analysis of the adsorption and diffusion of single Pb atoms has been carried out. The identification of the lowest energy adsorption sites has been made possible by means of the first-principles calculation, and the comparison between experimental and simulated STM images. The energy barrier for diffusion events between three regions inside the half-unit cells has been calculated and experimentally measured, finding a very good agreement between calculations and experiments.

Ge(111)-c(2x8): The diffusion of single vacancies on the Ge(111)-c(2x8) surface deliberately generated with the STM tip has been analyzed in a temperature range between 280 and 320K by measuring mean square displacements as a function of time from large series of STM movies (Fig. 2). The energetics and the complicated atomistic mechanisms of vacancy diffusion are presented and discussed in this work in comparison with previous measurements, limited to room temperature [8-9], and first-principles calculations on related systems [10]. As a final issue, it has also been demostrated that single vacancies can be created at temperatures as low as 40K [7]. As, at such low temperatures the vacancies do not diffuse anymore, this opens the possibility for future nanopatterning of this surface at the atomic scale.

References

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Figures

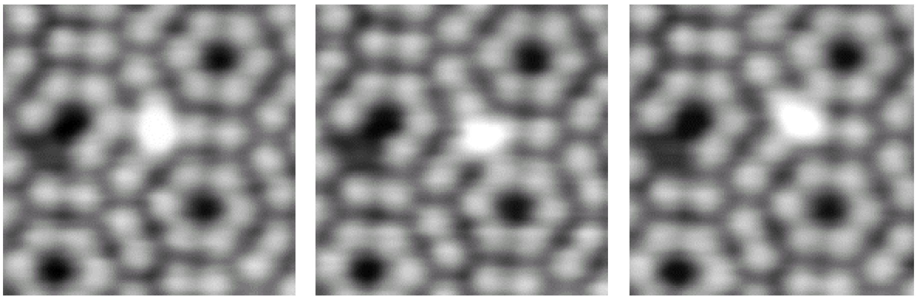

Fig 1: Images extracted from an STM movie measured on Pb/Si(111)-(7x7) at 108K showing the diffusion of a single Pb adatom betwen the three "basins of attraction" of the (7x7)-half-cell. The frame times are: (a) 0 s, (b) 21 s, (c) 124 s. The image size is 5.4 x 5.4 nm^2. The sample bias is 1.2 V and the tunnel current is 0.2 nA.

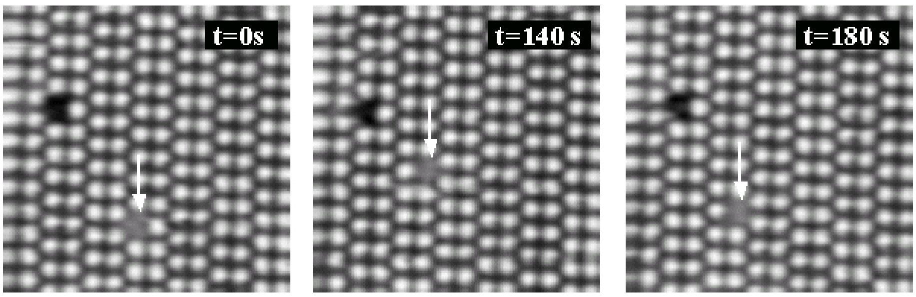

Fig. 2: Sequence of images extracted from an STM movie measured on Ge(111)-c(2x8) at 312K showing the diffusion of an STM artificially generated atomic vacancy (marked with an arrow). The black defect on the left does not move and it is used as a reference point. The scanning area is 10x10 nm^2, Vs = +1V, and It = 0.5 nA for all the images.